CURRENT TO VOLTAGE CONVERTER AND VOLTAGE TO CURRENT CONVERTER

PRESENTED BY TEAM 6

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DESIGN AND WORKING

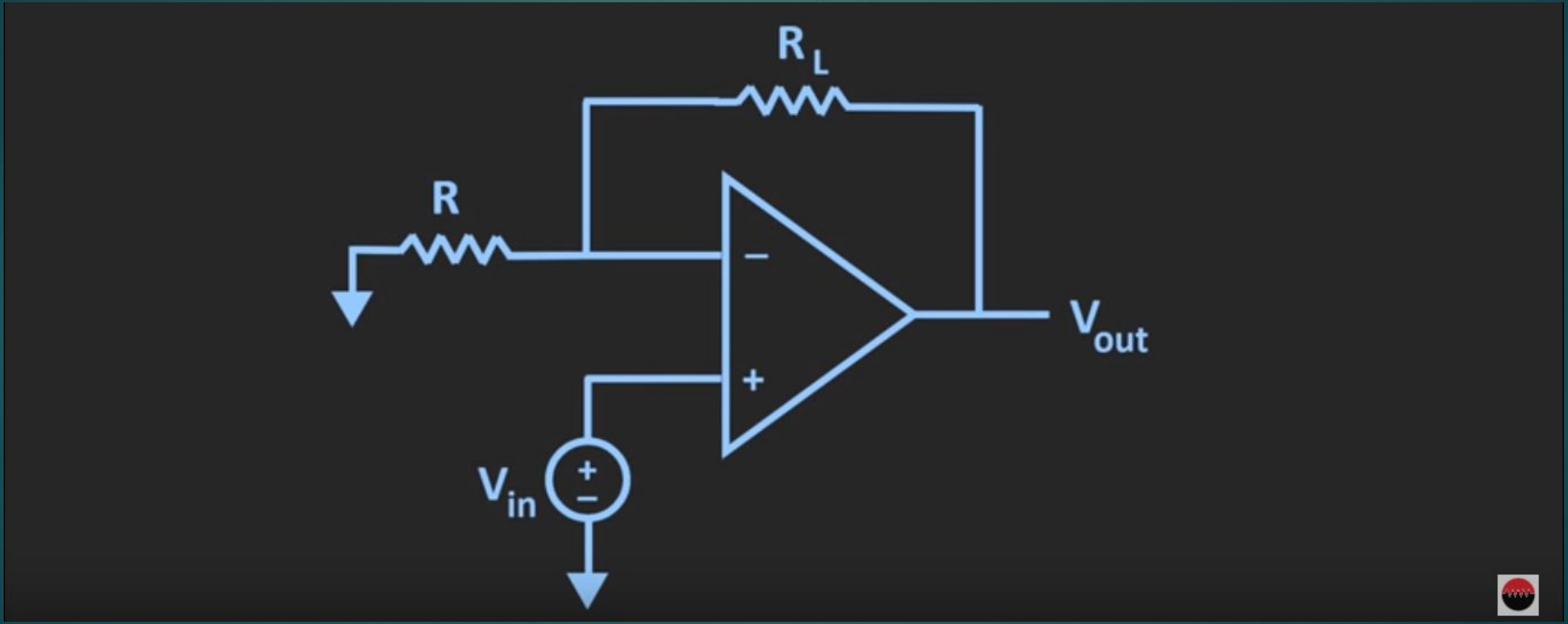
To make a voltage to current converter or vice versa we use an operational amplifier.

One may ask why do we need an operational amplifier instead of just connecting a voltage source and resistor in series.

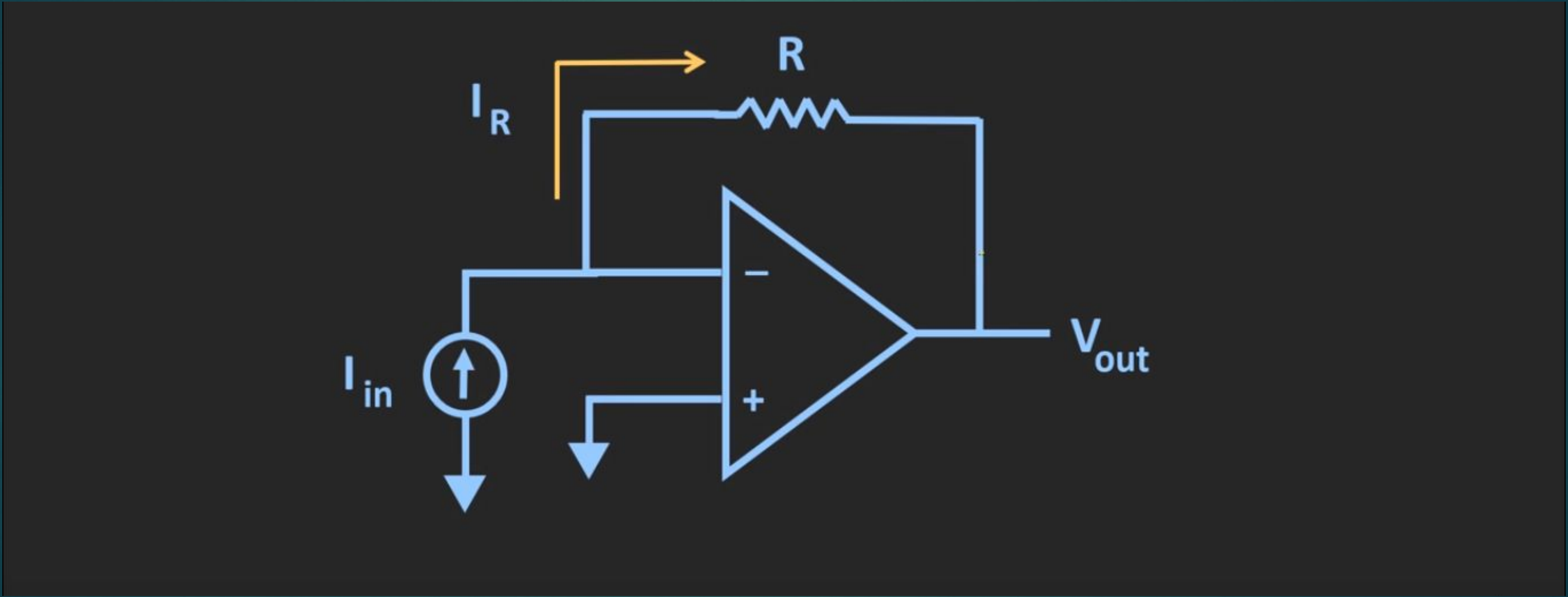
In this case the current across the load will depends on its overall impedence.

Now we will show you how we can use the op amp in this case.

Voltage to current converter



CURRENT TO VOLTAGE CONVERTER



DESIGNING AN OPERATIONAL AMPLIFIER

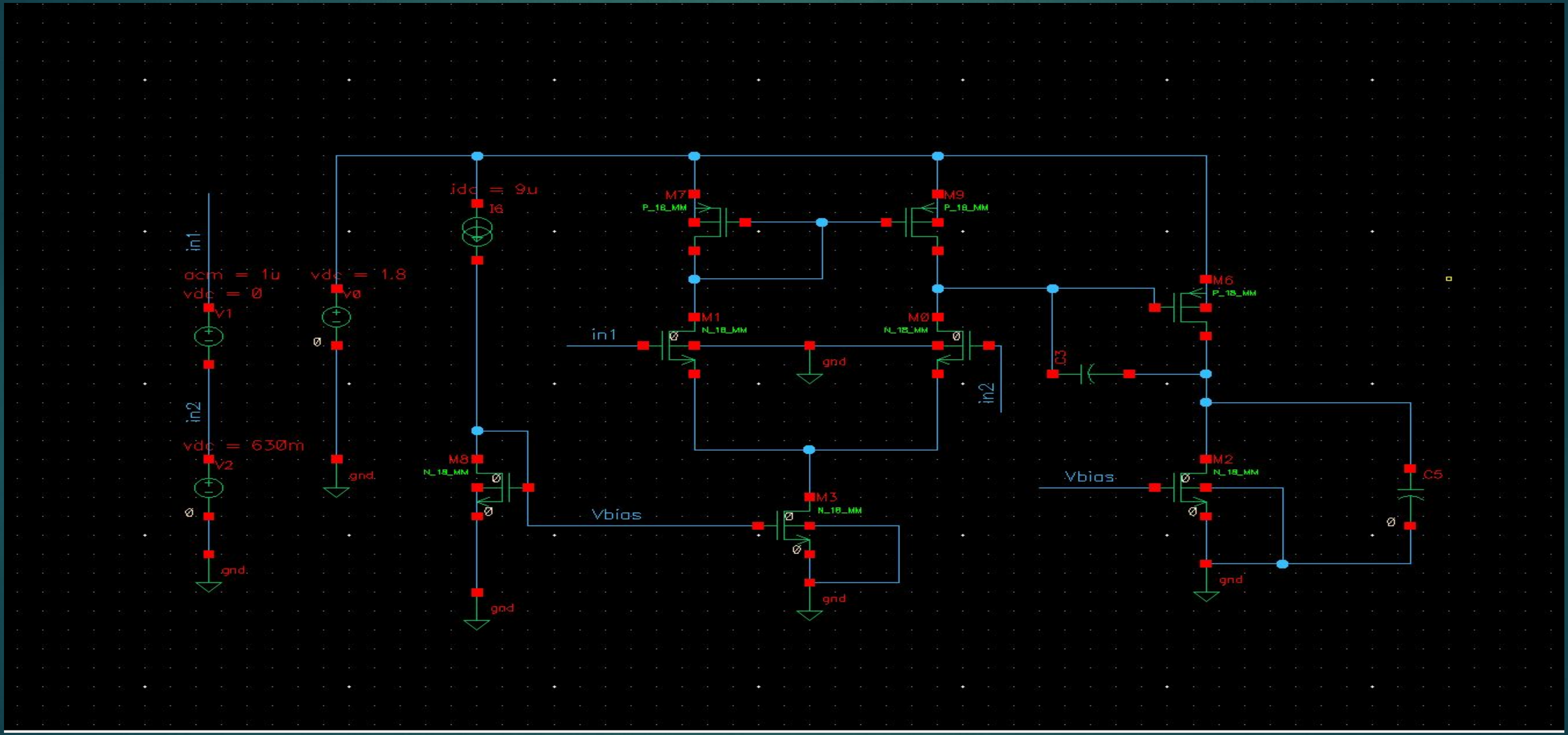
We have many stages in an operational amplifier.

The main aim of an amplifier is to have :

- High input impedence
- High gain
- Low output impedence

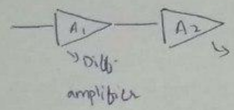
In the coming slides we will explain how we deal with each stage.

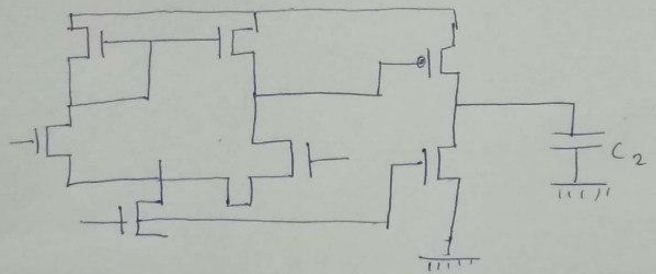
The Design



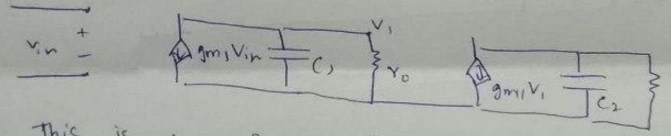
idc = 9u
I6
M7
P_18_MM
M9
P_18_MM
in1
acm = 1u
vdc = 0
V1
vdc = 1.8
V0
M6
P_18_MM
M1
N_18_MM
M0
N_18_MM
in1
gnd
C3
in2
in2
vdc = 630m
V2
gnd
M8
N_18_MM
Vbias
M3
N_18_MM
M2
N_18_MM
Vbias
C5
gnd
gnd
gnd
gnd

Differential Amplifier cannot provide enough gain.





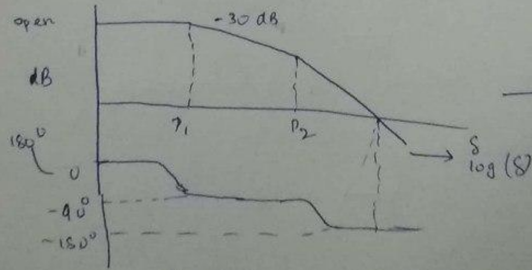
Small signal model

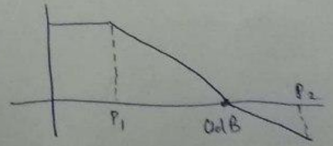


This is a 2 port system.

$P_1 = \frac{1}{r_{o1} C_1}$; $P_2 = \frac{1}{r_{o2} C_2}$;

Now, we draw the Bode plot.

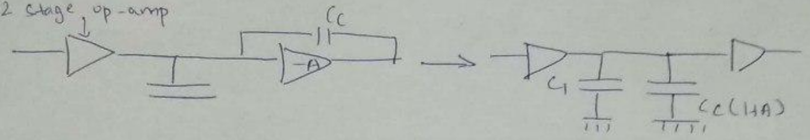




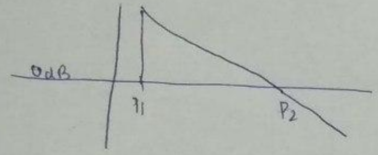
(Compensation)

There is a problem with the phase margin (must be $\geq 45°$)
For this, we do compensation and move the domain pole.

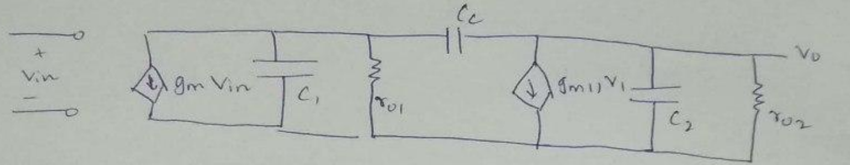
To move P_1, increase C_1, and to avoid a large capacitance, we use the Miller Effect.

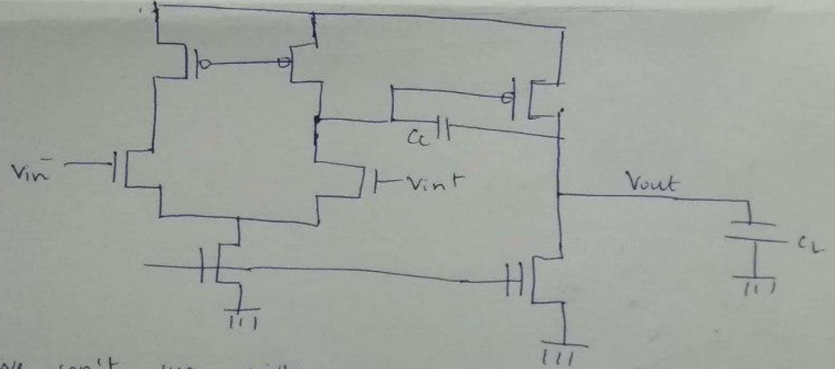


$P_1 = \frac{1}{r_1 [C_1 + C_C(1+A)]}$



New Circuit Diagram





We can't use miller theorem because of pole splitting

Method to find $\frac{V_o}{V_{in}} \Rightarrow \frac{V_1}{V_{in}} \times \frac{V_o}{V_1}$

$$\frac{V_1}{1/sC_1} + \frac{V_1}{R_1} + g_{m1}V_{in} + \frac{V_1 - V_o}{1/sC_2} = 0$$

$$V_1(sC_1 + 1/R_1 + sC_c) + g_{m1}V_{in} - V_o sC_c = 0$$

$$V_1 = \frac{V_0 \cdot sC_cR_1 - g_{m1}R_1V_{in}}{1 + sR_1(C_1 + C_c)} \quad \cdots (1)$$

Node analysis @ V_0

$$\frac{V_0}{1/sC_2} + \frac{V_0}{R_2} + g_{m2}V_1 + \frac{V_0 - V_1}{1/sC_c} = 0$$

$$V_0[s(C_2 + C_c) + 1/R_2] = V_1[sC_c - g_{m2}]$$

substitute (1) (V_1 value)

$$V_0[s(C_2 + C_c) + 1/R_2] = \frac{(V_0\, sC_cR_1 - g_{m1}R_1V_{in})(sC_c - g_{m2})}{1 + s(C_1 + C_c)R_1}$$

$$V_0[s(C_2 + C_c)R_2 + 1][1 + s(C_1 + C_c)R_1] = (V_0 \cdot sC_cR_1 - g_{m1}R_1V_{in})(sC_c - g_{m2})$$

$$\frac{V_0}{V_{in}} = \frac{g_{m1}R_1\, g_{m2}R_2\left(1 - \frac{sC_c}{g_{m2}}\right)}{s^2[R_1R_2(C_1C_2 + C_1C_c + C_2C_c)] + s[R_2(C_c + C_2) + R_1(C_c + C_1) + C_cg_{m2}R_2R_1] + 1}$$

~~Assume~~

$$\frac{V_0}{V_{in}} = \frac{A_{DC}\left(1 - \frac{s}{z}\right)}{(1 + s/p_1)(1 + s/p_2)} = \frac{A_{DC}\left(1 - \frac{s}{z}\right)}{1 + s\left(\frac{1}{p_1} + \frac{1}{p_2}\right) + s^2\left(\frac{1}{p_1p_2}\right)}$$

$$s\left(\frac{1}{p_1} + \frac{1}{p_2}\right) \approx s \cdot \frac{1}{p_1}$$

$$p_1 \approx \frac{1}{R_2(C_c + C_2) + R_1(C_c + C_1) + g_{m2}R_2R_1C_c}$$

③

$$p_1 \approx \frac{1}{g_{m2}R_2R_1C_c} \quad ; \quad (1^{st}\ \text{pole})$$

$$p_1p_2 = \frac{1}{R_1R_2(C_1C_2 + C_1C_c + C_2C_c)} \ ;$$

$$p_2 = \frac{p_1p_2}{p_1} = \frac{1}{\cancel{R_1R_2}[C_1C_2 + C_1C_c + C_2C_c]} \times g_{m2}\cancel{R_2R_1}C_c$$

$$p_2 = \frac{g_{m2}C_c}{\underbrace{C_1C_2 + C_1C_c}_{\text{small} \to \text{neglect}} + \underbrace{C_2C_c}_{\text{big}}} \approx \frac{g_{m2}\cancel{C_c}}{C_2 \cdot \cancel{C_c}}$$

$$p_2 = \frac{g_{m2}}{C_2} \quad ; \quad (2^{nd}\ \text{pole})$$

Using equations,

$$z = \frac{g_{m2}}{C_c} \ ; \quad p_1 = \frac{1}{g_{m2}R_1R_2C_c} \ ; \quad p_2 = \frac{g_{m2}}{C_2}$$

$$A_{DC} = g_{m1}R_1\, g_{m2}R_2$$

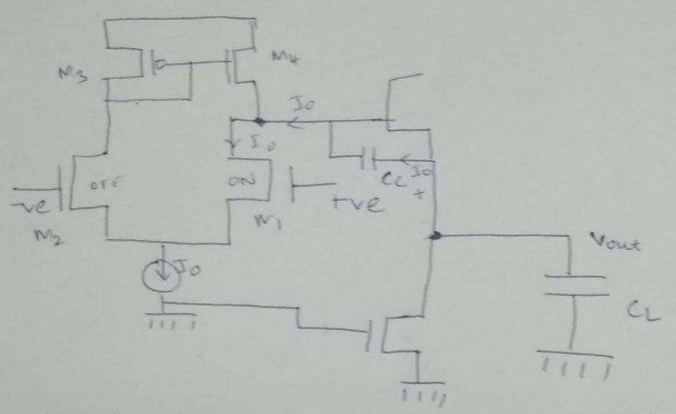
$$GBW = \text{DC gain} \times p_1 = \frac{g_{m1}R_1\, g_{m2}R_2 \times 1}{g_{m2}R_1R_2C_c}$$

$$GBW = \frac{g_{m1}}{C_c} \ ;$$

Slew rate

(on next page)

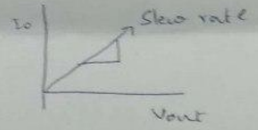
Circuit Diagram



First case:
For slew rate, M1 is ON and M2 is OFF

Io flows throw Cc

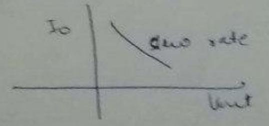
Slew rate $= \frac{I_o}{C_c}$



Second case

M2 is ON, M1 is OFF

Io flows through M4 because of current mirror
Io flows through Cc



$\boxed{\text{Slew rate} = \frac{I_o}{C_c}}$

Slew Rate calc

~~Slew rate~~ GBW $\frac{g_{m1}}{C_c}$

$\boxed{Z = \frac{g_{m2}}{C_c}}$

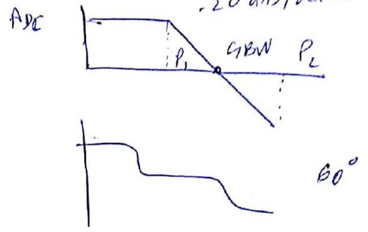
DC gain $\times P_1$

$\boxed{g_{m1} g_{m2} \cdot R_{O1} \cdot R_{O2}}$

$P_1 = \frac{1}{g_{m2} R_1 R_2 C_c}$

$P_2 = \frac{g_{m2}}{C_2}$

-20 dB/dec



Assumption

10 GBW = Z

$$\frac{A_{DC}\left(1-\frac{s}{Z}\right)}{\left(1+\frac{s}{P_1}\right)\left(1+\frac{s}{P_2}\right)}$$

Gain bandwidth is freq

60° wors.

$$\angle\frac{V_o}{V_{in}} = -\tan^{-1}\left(\frac{\omega}{Z}\right) - \tan^{-1}\left(\frac{\omega}{P_1}\right) - \tan^{-1}\left(\frac{\omega}{P_2}\right)$$

$Z \cong 10\,GBW$

$$-\tan^{-1}\left(\frac{GBW}{Z}\right) - \tan^{-1}\left(\frac{GBW}{P_1}\right) - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$-\tan^{-1}\left(\frac{1}{10}\right) - \tan^{-1}\left(\frac{g_{m1}}{C_c} \cdot \frac{g_{m2} R_1 R_2 C_c}{}\right) - \tan^{-1}\left(\frac{g_{m1}}{C_c}\frac{C_2}{g_{m2}}\right)$$

$$\angle\frac{V_o}{V_{in}} = -\tan^{-1}\left(\frac{1}{10}\right) - \tan^{-1}(A_{DC}) - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$-5.710 - 89.98 - \tan^{-1}$

$$-120 = -5.71 - 89.98 - \tan^{-1}\left(\frac{GBW}{P_2}\right)$$

$$\tan^{-1}\left(\frac{GBW}{P_2}\right) = 24.31$$

$$\frac{GBW}{P_2} = \tan(24.31) = 0.4513$$

$$P_2 = \frac{GBW}{0.4513} = \cancel{2.216}\ 2.27\,GBW$$

$\frac{g_{m1}}{C_c}$ $P_2 \geq 2.2\, GBW$

$\frac{g_{m2}}{C_2} \geq 2.2 \frac{g_{m1}}{C_c}$

C_2 is cap in second stage $= C_L$

As $z = 10 \frac{g_{m1}}{C_c}$ GBW

$\frac{g_{m2}}{C_c} = \frac{10 g_{m1}}{C_c}$

$g_{m2} = 10 g_{m1}$

$\frac{10 g_{m1}}{C_L} \geq 2.2 \frac{\cancel{g_{m1}}}{C_c}$

$C_c \geq 0.22 C_L$

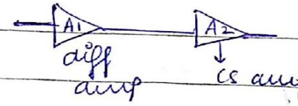
$\frac{10 C_c}{2.2} \geq C_L$

$\frac{9 p}{800 f}$

$\frac{9}{800} \times \cancel{10^{6}} \times 10^{9}$

$\cancel{90}\ \frac{9}{\cancel{8}} \times 10^{7}$ 1.12

Design of 2-stage op amp



If we use pmos - more swing

DC gain - 3165 ≈ 70dB

GBW = 30MHz

PM ≥ 50°

Slew rate = 20 V/μ sec

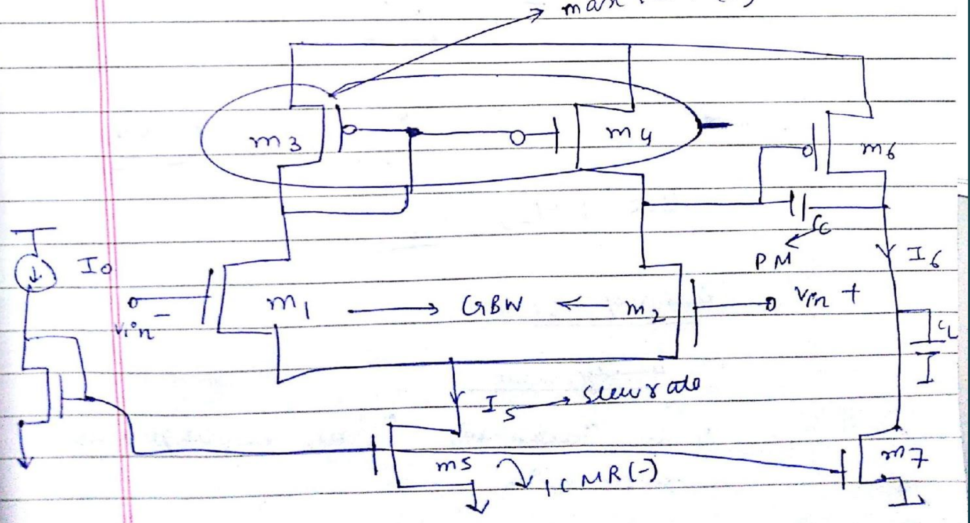
ICMR(+) = 1.6 V

ICMR(-) = 0.8 V

C_L = 2pF

Power ≤ 300 μ

use W/L in micro to prevent channel length modulation.



$C_c \geq 0.22\, C_L$ for $PM \geq 60$

① $C_c \geq 440\,fF$

$\downarrow$ Taking $800\,fF$

②

$SR = \frac{I_5}{C_c}$

$I_5 = SR \cdot C_c = \frac{20\,V}{\mu s} \times 800\,fF$

$= 16\,\mu A$

Taking 20 μA

$I_5 \approx 20\,\mu A$

Design of M_1, M_2

$g_{m1} = GB \times C_c \times 2\pi$

$g_{m1} = 30\,MHz \times 800\,f \times 2\pi$

$g_{m1} = 150.79\,\mu$

$g_{m1} = 160\,\mu$

$\left(\frac{W}{L}\right)_1 = \frac{g_m^2}{\mu_n C_{ox}\, 2 I_D}$

$= \frac{160^2}{300 \times 20} = 4.266$

Use $(W/L)_{12} = 5$

Design of m_3, m_4

m_3 always in sat

If we increase Vin− ↑, m_1 might go into triode region

$(V_d)_{m1} \geq V_g - V_{t1}$

$V_g < (V_{D1})_m + V_{t1}$

$V_{in} < V_{D1} + V_{t1}$

$V_{in\,max} = V_{D1} + V_{t1}$

$V_{D1} = V_{DD} - (V_{sg})_{m3}$

$I_3 = \frac{\mu_p C_{ox} (W/L)}{2} (V_{gs} - |V_t|)^2$

$V_{gs} = \sqrt{\frac{2 I_3}{\beta_P}} + |V_{t3}|$

$V_{D1} = V_{DD} - \left[\sqrt{\frac{2 I_3}{\beta_P}} + |V_{t3}|\right]$

$ICMR+ \leq V_{D1\,min} + V_{t1\,min}$

$\leq \left[V_{DD} - \left(\sqrt{\frac{2 I_3}{\beta}} + |V_{t3}|\right)\right]_{min} + V_{t\,min}$

$\leq V_{DD} - \sqrt{\frac{2 I_3}{\beta}} - |V_{t3}|_{max} + V_{t1\,min}$

$\mu_p C_{ox} = 60\,\mu$

$(W/L)_3 = \frac{2 I_{D3}}{\mu_p C_{ox} \left[V_{DD} - ICMR+ - V_{t3\,max} + V_{t1\,min}\right]^2}$

Using just diff amp with $(W/L)_3 = 20$, assuming

$I_{D_3} = 10\mu$

Putting $V_{t3max} = 0.51$

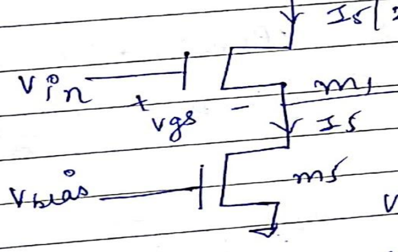
$V_{t1min} = 0.47$

$$\left(W/L\right)_3 = \frac{2 \times 10\mu}{60\mu\left[1.8-1.6-0.51+0.47\right]^2}$$

$$= 13.02$$

using ≈ 14

Design m_5



if $v_{in} \downarrow$

$v_{gs} \downarrow$

$V_o \downarrow$

$V_{DS} > V_g - V_t$ for m_5

if $V_D \downarrow$, m_5 will enter triode

$V_{in(min)} \geq v_{gs1} + V_{Dsat5}$

$ICMR_{(min)} \geq v_{gs1\,max} + V_{Dsat5}$

$$ICMR \geq \left[\sqrt{\frac{2I_{D1}}{\beta_1}} + V_{t1}\right]_{max} + V_{Dsat}$$

$$V_{Dsat} \geq ICMR - \sqrt{\frac{2I_{D1}}{\beta_1}} - V_{t1max}$$

$$V_{Dsat} \geq 0.8 - \sqrt{\frac{2 \times 10\mu}{300\mu \times 5}} - V_{t1max}$$

using new value

$$V_{Dsat} = 0.8 - 0.1154 - 0.59$$

$$= 94.6mV$$

$\downarrow$

Should be $\geq 100mV$

For saturation.

But we can't increase m_5

coz m_7 will increase

So, we can't do that otherwise gain decrease.

So we have to decrease $(W/L)_1 \approx 6$

$V_{Dsat} \approx 105mV$

$$(W/L)_5 = \frac{2 \times 20\mu}{300 \times (105mV)^2}$$

$$= 12.09$$

$(W/L)_5 \approx 12$

Design m_6

$g_{m6} \geq 10\, g_{m1}$

$g_{m6} \geq 10 \times 160 = 1600\mu$

$V_{DSm3} = V_{DSm4} = V_{DSm6}$

$V_{GSm3} = V_{GSm4} = V_{GSm6}$

$$\frac{(W/L)_6}{(W/L)_4} = \frac{g_{m6}}{g_{m4}}$$

$g_{m4} = \sqrt{60 \times 14 \times 2 \times 10}$

$= 129.61$

$(W/L)_6 = 172.82$

≈ 173

M7

$$\frac{I_6}{I_4} = \frac{(W/L)_6}{(W/L)_4}$$

$I_6 = 124.82$

$I_6 = 125\ \mu A$

$$\left.\frac{I_7}{I_5} = \frac{(W/L)_7}{(W/L)_5}\right\} \text{M}_5 - \text{M}_7 \text{ same } \underline{V_{GS}}$$

$(W/L)_7 = \underline{75}$